

## Delayed Mortality of Barged Snake River Fish ( $D=0.5$ )

Salmon lay their eggs (spawn) in freshwater streams and then die shortly thereafter. The juveniles hatch out around 6 months later, rearing in freshwater for some time, and then migrate to the ocean (smolt stage). After 1-3 years in the ocean, these fish return to the same freshwater streams to spawn and die. Based on counts of spawning salmon in freshwater streams and returning adults from these original spawners (offspring), we can estimate the survival of salmon over their life cycle. We can also compartmentalize that survival into the various life stages: 1) egg to juvenile (rearing in freshwater), 2) survival during downstream migration (smolt stage), 3) survival in the estuary and early ocean, 4) survival during upstream migration as adults.

For some of the life stages, we have data that allow us to estimate the direct mortality that occurs in that life stage (how many fish die). For example, for fish that are harvested in the ocean and in freshwater, we have records that allow us to estimate how many fish were caught and killed and thus what the survival of salmon was in that life stage. Mortality that occurs in the same life stage as the cause of the mortality is called direct mortality, as it occurs immediately in that life stage. What is less certain and more difficult to estimate, however, is how a fish's experience in one life stage may affect its survival in a later life stage. This mortality is called delayed or extra mortality and is similar to the case where a human who smoked cigarettes when they were younger, later dies of lung cancer. That person does not die at the moment they smoke their first cigarette, but they may die later as a result of the interaction between this earlier experience and long term health and fitness.

In the Snake and Columbia rivers juveniles and adults must migrate past 8 hydroelectric dams on their way to and from the ocean (**Figure 1**). Not all fish can successfully migrate past the dams. Some are killed by turbines, and some are killed by predators in the reservoirs below the dams. The direct mortality that occurs when these juveniles migrate past each of the dams determines the survival in that life stage. The dams have sensors that can detect juvenile salmon with PIT tags, which allows us to estimate the survival from the top of the hydrosystem in the Snake River (from the uppermost dam, Lower Granite Dam) down to the lowermost dam in the Columbia River, near the estuary (Bonneville Dam), or over some stretch in-between. Because the direct mortality rate of juvenile fish that attempt to migrate past the dams is so high (~50-80% of the fish die), the National Marine Fisheries Service has been attempting to transport juvenile salmon around the dams. The juveniles are generally collected at the three uppermost dams on the Snake River (Lower Granite) and transported by barge or truck down-river and released below Bonneville dam.

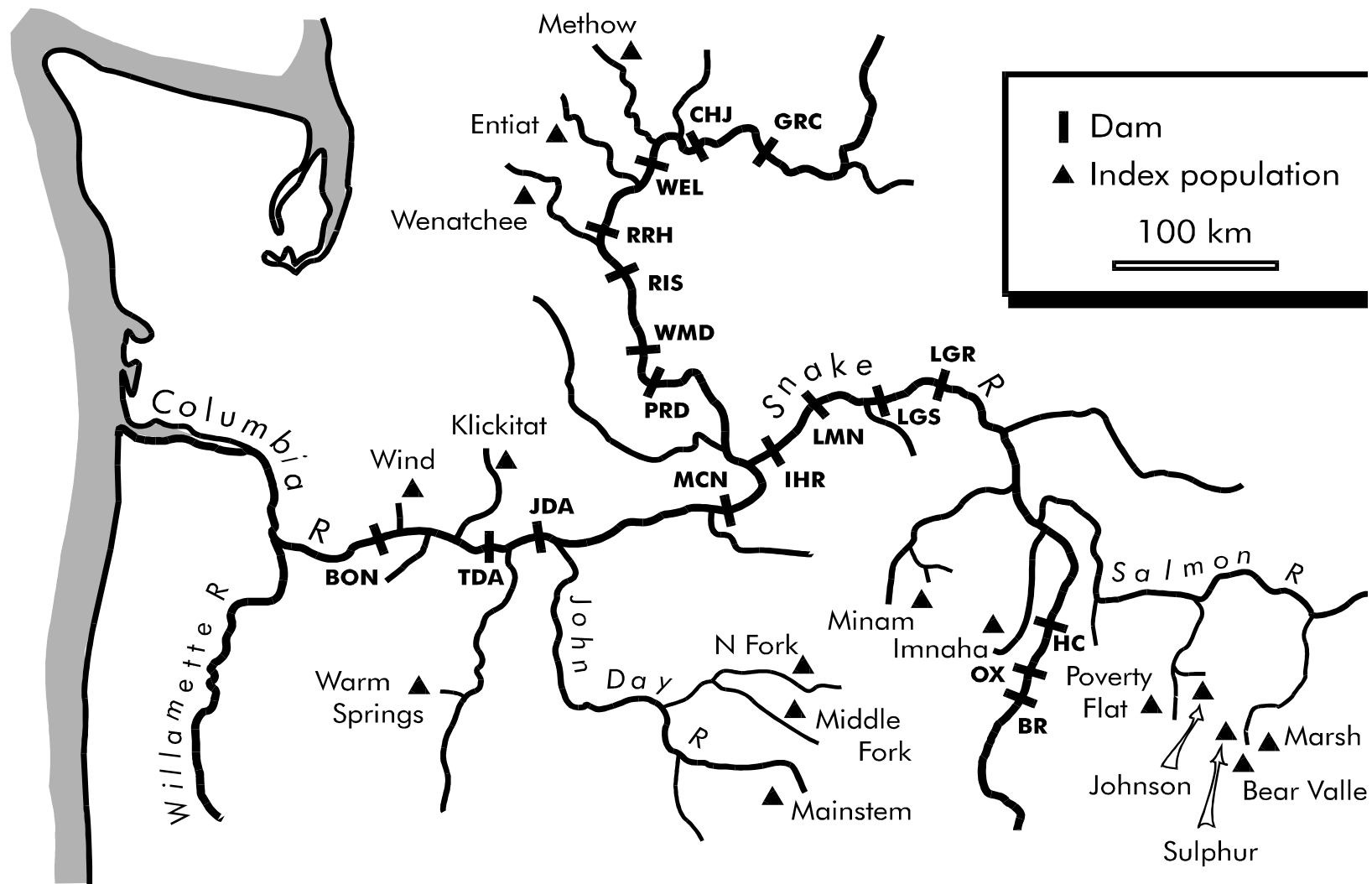
The direct mortality of fish that are transported around the dams (from collection at Lower Granite Dam to release below Bonneville Dam) appears to be quite low

(close to 2%). This mortality of transported fish is considerably lower than the direct mortality of fish that travel in the river and have to migrate past the dams (~50-80%). However, as discussed above, this direct mortality is only one component of the overall survival to adult spawners. It is the overall survival to adults that describes the effectiveness of transportation and the effects of in-river passage past dams. The quantity which describes the difference between the delayed mortality of transported fish and fish that migrate in-river, is called 'D' (a ratio). 'D' would be equal to 1 if there were no difference between the two groups of fish. When the fish that traveled in-river survive better from the time they leave the hydrosystem to the time they return as adults, then 'D' is less than one.

For example, if the direct mortality of the transported fish were 0% and the direct mortality of the in-river fish were 50%, we would expect the transported fish to survive at 2 times the rate of in-river fish (because we lost 50% of the in-river fish in the hydrosystem). If the overall survival for the transport fish is 2 times that for in-river fish, there is no difference in the delayed mortality between the two groups ( $D=1$ ). In this case, the fish survive at the same rate in the estuary and early ocean, regardless of whether they were transported or migrated in-river. However, for the same example, if the overall survival was the same for the transport and in-river groups (was not 2 times greater for transport fish), then the delayed mortality of transported fish must be twice as high compared to in-river migrating fish (again, because we lost 50% of the in-river fish in the hydrosystem). In this case,  $D=0.5$  and the survival of transported fish, from the time they leave the hydrosystem to the time they return as adults, is only half that of the fish that migrated in-river. A schematic diagram showing the case where 'D', the delayed differential mortality of transported fish relative to fish that migrated in-river is 0.5 is shown in Figure 2.

For both groups of fish, those that were transported and those that traveled in-river, some scientists believe that the delayed mortality that occurs in the estuary and early ocean is related to their experience either through the hydrosystem or during collection and transportation. Due to the stress of collection and bypass at the dams, and crowding during transportation in a barge or truck, transported fish may be more vulnerable to disease and predators later in life. Similarly, fish that travel in-river must successfully migrate past the turbines, bypass systems, and reservoir predators of eight hydroelectric dams. Stress or injury from this experience may also cause the fish to be vulnerable to disease and predation, either later down in the hydrosystem or while the fish are in the estuary and ocean. Some data indicate that the delayed or extra mortality of fish populations that migrate past 8 hydroelectric dams may be much greater than that of fish populations with similar characteristics from lower down in the system, where they migrate past only 4 hydroelectric dams. Because of this difference, scientists hypothesized that hydrosystem experience, whether in the barge or in-river, increases the delayed mortality of fish that occurs in the estuary or early ocean life stage.

There are important implications of delayed or extra mortality when evaluating the outcome of management actions for spring/summer chinook. Extra mortality and 'D' are not explicitly modeled in the CRI approach; however, the overall outcomes are generally similar to those that result from the PATH approach. If there is a significant delayed mortality of transported fish (low 'D') relative to in-river fish, then drawdown of Snake River dams has a high probability of recovering these stocks under both PATH and NMFS CRI models. If there is no or little delayed mortality of transported fish (high 'D'), and the extra mortality of in-river fish is related to their hydrosystem experience, then drawdown still has a high probability of recovering salmon. The CRI effort does not explicitly employ the concepts of D and extra mortality in their analytical framework, in part, because NMFS scientists estimate that 'D' is high. Instead, CRI points out that it appears that removal of four dams must increase survival below Bonneville ('D' and extra mortality in PATH) by 60-120% (depending on other assumptions about current conditions), and asks what field data (without reference to models) support the conclusion that such a large improvement can be made. In PATH, drawdown has a low probability of recovering these fish only if there is no difference between the survival of transported and in-river fish from the time they left the hydrosystem until they returned as adults ( $D=1$ ) and the overall survival of both groups is unrelated to hydrosystem experience. The assumed value of 'D' and whether or not the extra mortality of in-river fish is related to hydrosystem experience changes the overall effectiveness of drawdown as a management action for spring/summer chinook.

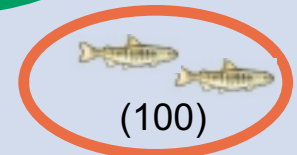
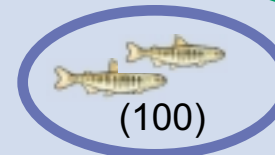
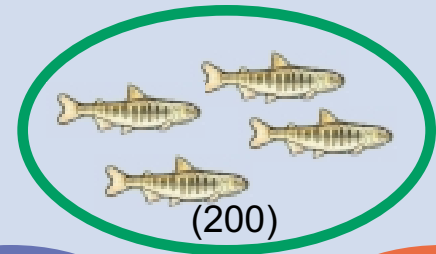


**Figure 1. Map of the Columbia and Snake Rivers showing the 8 hydroelectric dams from Lower Granite Dam on the Snake down to Bonneville Dam, the lowermost dam on the Columbia River.**

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*Freshwater*



Start life cycle (5)

(5)

End life cycle (3)

(3)

Lower Granite Dam

Little Goose Dam

Lower Monumental Dam

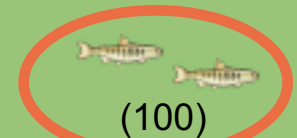
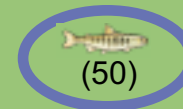
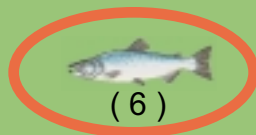
Ice Harbor Dam

McNary Dam

John Day Dam

The Dalles Dam

Bonneville Dam



*Ocean*

